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## CONCENTRATIONS OF SELECTED CONTAMINANTS IN CABIN AIR OF AIRBUS AIRCRAFTS

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### Abstract

The concentrations of selected air quality parameters in aircraft cabins were investigated including particle numbers in cabin air compared to fresh air and recirculation air, the microbiological contamination and the concentration of volatile organic compounds (VOC). The Airbus types A310 of Swissair and A340 of Lufthansa were used for measurements. The particles were found to be mainly emitted by the passengers, especially by smokers. Depending on recirculation filter efficiency the recirculation air contained a lower or equal amount of particles compared to the fresh air, whereas the amount of bacteria exceeded reported concentrations within other indoor spaces. The detected species were mainly non-pathogenic, with droplet infection over short distances identified as the only health risk. The concentration of volatile organic compounds (VOC) were well below threshold values. Ethanol was identified as the compound with the highest amount in cabin air. Further organics were emitted by the passengers - as metabolic products or by smoking - and on ground as engine exhaust (bad airport air quality). Cleaning agents may be the source of further compounds.

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### Introduction

Air quality on airliners has become an important issue during the past years. Especially American newspapers but also the European press have frequently reported on potential deterioration of air quality due to the introduction of recirculation systems onboard modern commercial aircraft types. So far performed measurements of air quality, however, have not provided sufficient knowledge about the following contaminants:

- particle numbers in fresh and recirculation air and in the aircraft-cabin
- types and amounts of microbiological contaminations
- types and amounts of volatile organic compounds (VOC)

The reported measurements therefore focussed on these three types of contaminants.

### Selected Aircraft Types

The aircraft types Airbus A310 of Swissair and the Airbus A340 of Lufthansa were selected for the measurements for the following reasons:

- installation of different air distribution systems: While the A310 has got local mixing of fresh and recirculation air with an extraction of used air from the ceiling area, the A340 is equipped with a central mixing unit, sucking recirculation air from the underfloor area in front and after the wings.
- The recirculation filters represent different generations of filter systems. The A310 filter has a performance corresponding to filter Class EU9 (clean room filter, efficiency at  $0.5 \mu\text{m}$  90%) while the A340 is equipped with an EU13 filter (highly efficient particulate air filter (HEPA), efficiency at  $0.3 \mu\text{m}$  of more than 99.97%).
- Both aircrafts are used for medium-distance and long-distance flights. Accordingly flight-time dependent concentrations of contaminants can be determined.

Both airlines have a high standard of maintenance (e.g. filter removal on time) and appropriate cabin cleaning, allowing the assessment of the measured air quality parameters.

#### Part I: Particle Counting

##### Description of the particle counters (custom made model by DEHA)

Fixed installed equipment was necessary to perform the measurements. It consisted of eight particle sensors, a pressure transducer for flight phase indication and a central unit for power supply and data storage. The measuring principle of the particle sensors is based on a laser optic counting the particle numbers in the air conducted through the sensor. Particles with more than  $0.5 \mu\text{m}$  in diameter could be detected. This system had been installed in the aircraft for about one year providing results during normal inservice flights.

Inside the cabin six particle sensors were installed. Two of them were located in the first class (A310)/business class (A340), two in the economy class non-smoker and two in the economy class smoker. The air intakes of the sensors were located between two middle-hatracks (ceiling sensors) and close to the floor level behind the dadopanel (floor sensors). Another sensor was installed in the fresh air duct downstream the air conditioning pack and a further one in the recirculation air duct of the cabin air distribution system downstream the recirculation filter (figure 1-2).

A310 Swissair Seatlayout

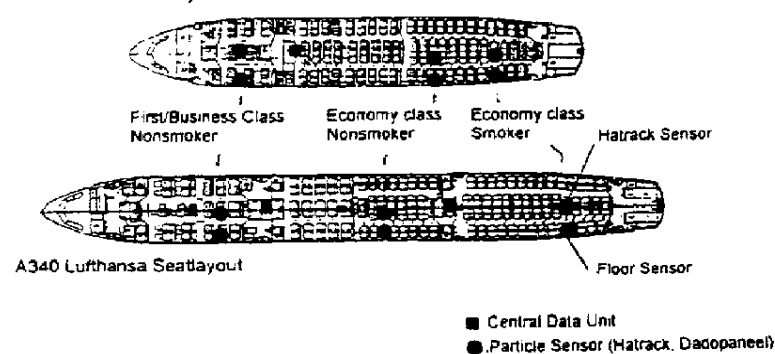


Fig. 1: location of sensors and central unit in A310 and A340

In the A310 the re-circulation) The re-air is a mixture of the

##### Results of particle co

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- 25 minutes after t
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In the A310 the recirculation air sensor mainly measured the air of the economy class smoker (zonal recirculation). The recirculation air intake of the A340 was located in the underfloor area. Here, the recirculated air is a mixture of the outgoing air of all cabin classes.

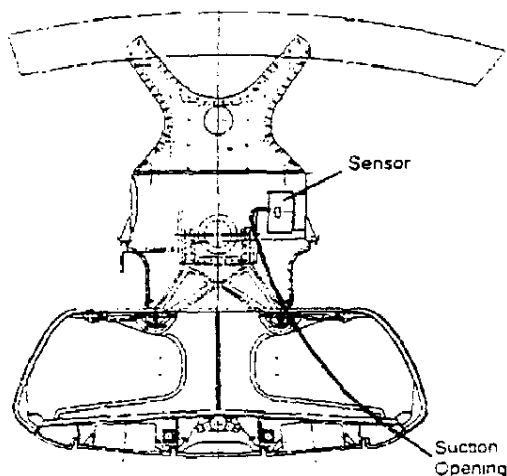


Fig 2: sensor installation hatrack A310/A340

#### Results of particle counting

The data were taken separately according to the following flight phases:

- 25 minutes before take off
- 25 minutes after take off
- cruise condition
- 25 minutes before landing
- 25 minutes after landing

The mean values were analysed and compared as shown in figures 3-5. The following statements can be concluded:

Generally the particle concentration highly depends on flight phase and passengers activity, respectively. Accordingly peak concentrations considerably surpass cabin mean values, during night flights they are substantially lower. For both aircraft types the mean particle concentration within the recirculation air was either lower or equal compared to the concentration in fresh air for all ground/flight cases.

The A310 ventilation system is separated in three cabin zones, each of which is equipped with a local recirculation filter. Recirculation air of lower quality was selected for the measurements. Purified with an EU9 filter even the „bad“ air is less contaminated than fresh air before and after take off and before and after landing. During cruise the contamination of fresh and recirculation air was found to be the same.

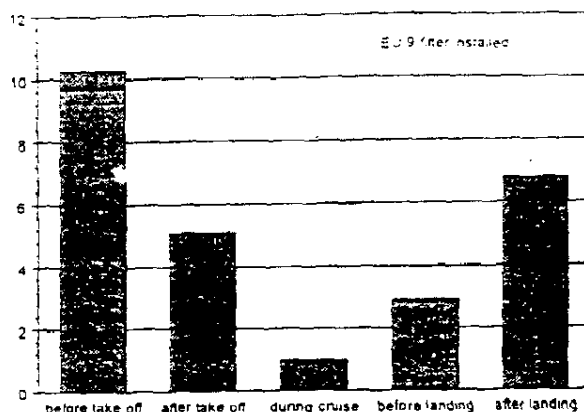


Fig 3: relation of particle contamination fresh-/recirc-air in A310

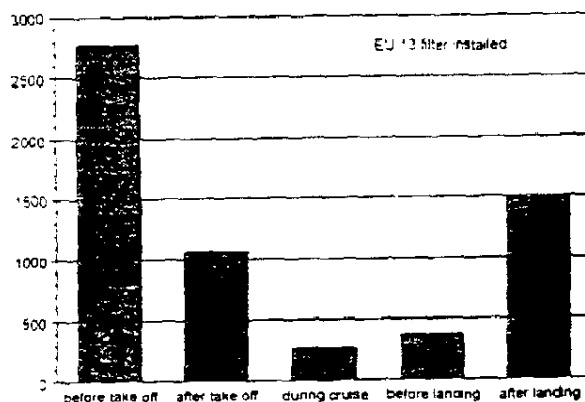


Fig 4: relation of particle contamination fresh-/recirc-air in A340

With the HEPA filter used at the A340 aircraft with a central recirculation system the concentration ratio between fresh and recirculation air was determined to be between 250 during cruise and 2800 before take off. The different ratios for ground and flight phases are mainly due to the substantially lower particle concentration outside the aircraft in higher altitudes. Higher ratios determined before take off compared to ratios measured after landing are caused by aircraft queues at the taxi way.

On ground the concentration of particles in fresh air was measured to be between  $10^6$  and  $10^7$  particles per  $m^3$ , which is in the lower range of expected outside concentrations in the investigated size range of  $> 0.5 \mu m$

diameter. Thus, the air supplied to the bleed air system compared to the air in the A310 cabin the smokers section is taken for comparison. The particles than supply a source of emissions.

Fig 5: comparison of bleed air to cabin air

Due to prohibition of smoking on aircraft, a slightly increase can be permitted, the ratio is during heavy smoking.

#### Part II: Microbiology

In many newspaper articles the recirculation system is

#### Measuring Methods

Measurements of particle concentration are different to the data

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diameter. Thus, the engine compressor as well as the fresh air flow source do not emit high amounts of particles to the bleed air system. As expected, during cruise the concentration outside the aircraft was considerably lower compared to the air on ground.

In the A310 cabin the sensors were located in the first class (six abreast), economy class (eight abreast) and in the smokers section of the economy class. The average concentrations of the haltrack and floor sensors were taken for comparison with supply air. As expected, the cabin air was substantially higher contaminated with particles than supply air (mixture between fresh and recirculated air). The passengers are therefore the main source of emissions.

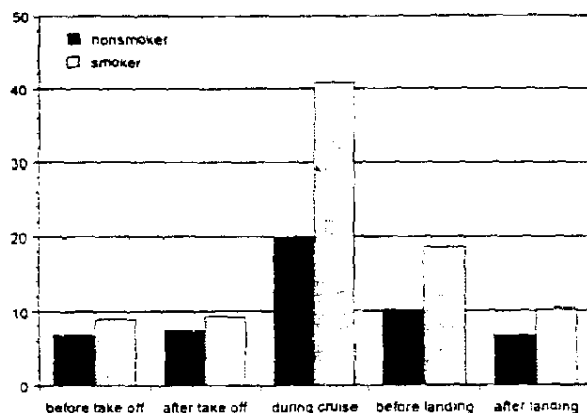


Fig 5. comparison of particle contamination economy class nonsmoker / economy class smoker relative to supply air in A310

Due to prohibition of smoking on ground the concentration in the smoking section was only slightly higher; the slightly increase can be explained by dust contamination of the smokers clothes. During flight, when smoking is permitted, the ratio of the mean concentration smoker/non-smoker increases (figure 5). Peak concentrations during heavy smoking phases, e.g. after meals, are significantly higher.

## Part II: Microbiological Contamination

In many newspaper articles high microbiological contamination and spread of bacteria and other germs through recirculation systems are supposed to be a substantial health risk for air passengers.

### Measuring Methods

Measurements of microbiological contaminations were performed during A310 and A340 scheduled flights. Different to the determination of particles, a portable device (Silt impactor FH2) was used.

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The air flow through the device was set at 50 l/min for two minutes. The cut-off value of the equipment was found to be 0.65  $\mu\text{m}$ . This value is an important factor for comparing results of different studies since it describes the diameter at which germs are excluded at 50% retaining capacity. Smaller germs are detected with a probability of less than 50%, larger ones with more than 50% probability. A low cut-off value indicates a reliable measurement device. The cut-off value of the equipment used in this study is very low compared with commonly used equipments for germ investigation with reported cut-off values between 0.65 and 3.80  $\mu\text{m}$ . As the usual bacteria size is known to be between 0.3 to 3.5  $\mu\text{m}$ , the cut-off value has a significant influence on the detected concentration.

During the present study 181 measurements on germ content were performed. The following agar plates were used to detect the germs:

- Blood agar: total bacterial germs
  - Blood agar/CO<sub>2</sub>-atmosphere: anaerobic germs
  - Xylose-Lysine-Desoxycholate (XLD) agar: salmonellae
  - Caseine-peptone-Soyapeptone (CPS) agar: thermophilic actinomycetes
  - R<sub>2</sub>A agar (deficient culture medium): environmental germs in a humid milieu
  - Nutrient agar: robust germs in air or dust
  - Sabouraud-(4%)Glucose (SA) agar: moulds (mesophilic and thermotolerant)
- The detection of airborne viruses is not feasible with the portable equipment used.

#### Results of microbiological measurements

The majority of the detected bacteria were non-pathogenic gram positive cocci. Non pathogenic aerob spore forming bacteria were much less prevalent. Micrococci and gram negative bacteria could only be detected at extremely low levels. Neither salmonella nor thermophilic actinomycetes (gram positive bacteria, mainly pathogen or allergen) were detected in cabin air. Staphylococcus aureus was not found, whereas staphylococcus epidermis was detected in some cases. Mould spores were measured at extremely low concentrations.

Contaminations in ventilation air were very low due to the high efficiency of the recirculation filters and the contamination free air in high altitudes. The geometric mean value for the supply air is found to be 76 Colony Forming Units (CFU) per cubicmeter for the A310 cabin and 28 CFU/m<sup>3</sup> for the A340 cabin. The recommended germ concentration in ventilation air in hospitals is < 50 CFU/m<sup>3</sup> for operating theatres and < 150 CFU/m<sup>3</sup> for dispensation rooms and intensive care rooms. Accordingly, the ventilation air for the A340 cabin fulfills the recommended germ concentration for operating theatres which is nearly reached even by the A310 cabin tackled with less efficient filters. Apprehension about an infection risk through ventilation systems therefore is not reasonable.

The bacteria concentration was higher in the economy class than in business or first class. The main emitters of bacteria therefore are the passengers. The geometric mean values for bacteria per flight are given in table 1 (i.m. individual measurements, not mean values):

Table 1: Detected germ content of measurement

|                       |
|-----------------------|
| Cockpit during flight |
| First class (i.m.)    |
| Business class        |
| Economy class         |
| Galley                |
| Lavatory (i.m.)       |
| Outside Geneva air    |
| Outside Abidjan/ivo   |

The detected concentrations indoor spaces, for which the concentration at Abidjan/ivo is less than all mean values measured. Reasons for bacteria peak: suitable efficient ventilation. Seven measurements were concentration (second value shows the proven efficiency

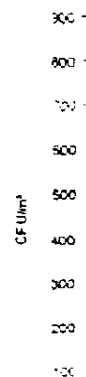


Fig. 6: typical

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Table 1: Detected Colony Forming Units inside and outside aircraft cabin

| point of measurement                                 | Colony Forming Units (CFU/m <sup>3</sup> ) |
|--|--|
| Cockpit during flight                                | 0 - 370                                    |
| First class (i.m.)                                   | 90 - 400                                   |
| Business class                                       | 75 - 443                                   |
| Economy class  | 38 - 1703                                  |
| Galley   | 30 - 1703                                  |
| Lavatory (i.m.)                                      | 20 - 790                                   |
| Outside Geneva airport (cold and dry air)            | 140  |
| Outside Abidjan/Ivory coast (hot air, 100% humidity) | > 10000                                    |

The detected concentrations are either within the lower range of values or below values measured in other indoor spaces, for which typical mean concentrations between 500 and 3000 CFU/m<sup>3</sup> are reported. The concentration at Abidjan/Ivory coast airport was higher (grass at the agar plate, too high for exact detection) than all mean values measured in cabin.

Reasons for bacteria peak concentrations are sneezing, coughing or even movement of the passengers. A suitable efficient ventilation system has to insure a fast reduction of the bacteria as shown in figure 6.

Seven measurements were performed successively. Figure 6 shows that a sudden increase of the bacterial concentration (second value) has decreased to normal range already three minutes later (third value). This shows the proven efficiency of the aircraft ventilation system.

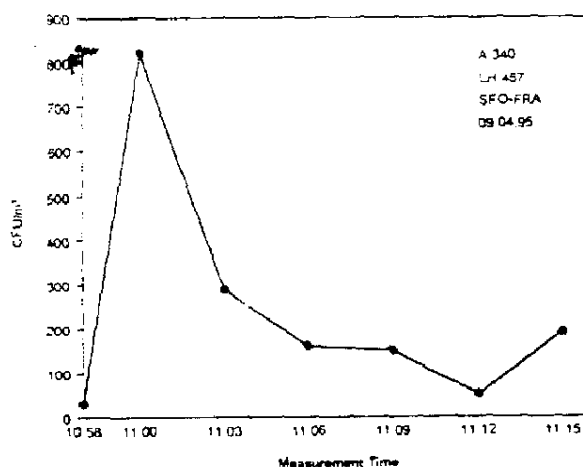


Fig. 6: typical progress of bacteria concentration in cabin air after a peak concentration

The main statements about the results of the microbiological measurements given by the Institute for Hygiene and Environmental Medicine at Medical University of Lübeck, Germany [1] are:

- Non-pathogenic cocci and spore forming bacteria at maximum levels of  $10^2 - 10^4$  CFU/m<sup>3</sup> are irrelevant to health considerations
- The only actual health risk is the person to person contact. By sneezing or coughing the infection is transmitted over short distances via droplets
- Mould spores in the measured amounts therefore are irrelevant to health considerations. No ventilation system is able to prevent this kind of transmission.

Apprehension about an increased infection risk in aircrafts compared to other crowded spaces is not reasonable.

### Part III: Volatile Organic Compounds

While particles - including bacteria and other germs - are removed by recirculation filters, the gaseous compounds are not filtered within the recirculation loop. As some of the volatile organic compounds (VOC) can cause malodours, high concentrations influence the comfort.

The detection of VOC was performed in parallel to the microbiological measurements. An active measurement method using suction pumps and adsorber tubes was applied.

The proceeding in measuring VOC is highly dependent on the expected compounds and their concentrations. To detect as many compounds as possible and keep them qualifiable and quantifiable, many different types of adsorber tubes and suction flows are necessary. The following adsorber tubes, extraction solvents and evaluation methods were used:

- Activated carbon tubes (NIOSH 100/50 mg) with carbon disulfide as extraction solvent. Evaluation by gas chromatography/mass-spectrometry (GC/MS) and gas chromatography/ atomic-emission detector (GC/AED) coupling. Detection of highly volatile, non- to semi-polar compounds.
- Tenax tubes (NIOSH 30/15 mg) with hexane as extraction solvent. Evaluation by GC/MS and GC/AED coupling. Detection of highly- to semi-volatile, non- to semi-polar compounds.
- Silica gel tubes (NIOSH 140/70 mg) with methanol as extraction solvent. Evaluation by GC/MS and GC/AED coupling. Detection of highly- to semi-volatile, semi-polar to polar compounds.
- ATD-Tenax tubes (175 mg) with automatic thermal desorption (ATD). Evaluation by GC/MS coupling. Detection of highly- to semi-volatile, non- to semi-polar compounds.
- Silica gel tubes coated with di-nitrophenylhydrazine (300/150 mg) with acetonitrile as extraction solvent. Evaluation by high-pressure liquid chromatography/UV-detector (HPLC/UV) coupling. Detection of aldehydes.

When using tubes for solvent extraction the sampling time must be several hours, because the concentrations of most VOC are in a lower ppb-range. Therefore only mean values for the concentration of VOC can be determined. Using ATD-tenax tubes with thermal desorption (higher sensitivity technique) the sampling time can be reduced to less than one hour. In this case it is possible to evaluate the concentration progress during different flight phases. The air samples were analysed by Fraunhofer Institute for Environmental Chemistry and Ecotoxicology in Schmallenberg, Germany [2].

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64 different compounds following main compounds:

- **Ethanol:** the compounds 593 ppb; threshold beverages
- **Acetone:** detected 500,000 ppb; origin
- **Toluene:** concentration 50,000 ppb; origin
- **Formaldehyde:** detected indoor limit value of aldehydes were detected
- **Acetic acid:** found 10,000 ppb; origin
- **Nicotine:** determined ppb; origin: smoking

The concentrations of dependent concentrations. Two examples are given.

64 different compounds have been detected, most of them in concentrations too low for quantification. The following main compounds (amounts, threshold values and possible origins) were found.

- **Ethanol:** the compound with the highest concentration determined (149 - >1780 ppb); geometric mean value 593 ppb; threshold value (MAK = maximum workplace concentration) 1 000 000 ppb; origin: alcoholic beverages.
- **Acetone:** detected concentrations 3 to 236 ppb; geometric mean value 24 ppb; threshold value (MAK) 500 000 ppb; origin: smoking, metabolic product.
- **Toluene:** concentrations between 2 to 135 ppb; geometric mean value 18 ppb; threshold value (MAK) 50 000 ppb; origin: mainly fuel ingredient, smoking.
- **Formaldehyde:** detected amount 3 to 26 ppb; geometric mean value 7 ppb; threshold value (MAK) 500 ppb; indoor limit value of the BGA (German Health Agency) 100 ppb; origin: smoking, cleaning agents. No other aldehydes were detected.
- **Acetic acid:** found in concentrations of 4 to 11 ppb; geometric mean value 6 ppb; threshold value (MAK) 10 000 ppb; origin: meals, cleaning agents.
- **Nicotine:** determined concentrations 0.2 to 26 ppb; geometric mean value 2 ppb; threshold value (MAK) 70 ppb; origin: smoking.

The concentrations of the detected compounds depend on the flight phase according to their origin. As the flight dependent concentrations are measured only during one single flight, the figures indicate not more than a trend. Two examples are given in figures 7 and 8: nicotine and the sum of aliphatics.

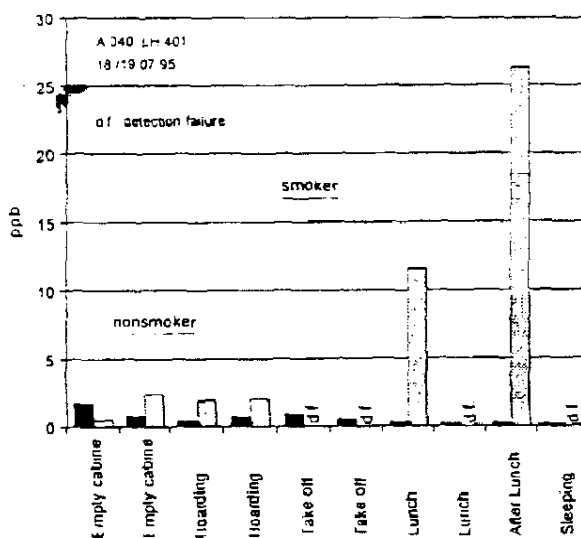


Fig.7. concentration progress of nicotine

Nicotine was found in low concentrations during the ground-phase, when smoking is prohibited. The maximum concentration reached one third of the MAK-value and was registered in the smoker section of the economy class after a meal, when nearly all smokers are smoking commonly. In the non-smoking section the nicotine concentration remains at very low levels. This shows an effective separation of the cabin atmospheres between smoking and non-smoking area.

Aliphatics (n-hexane, n-octane and higher hydrocarbons) are commonly detected as fuel ingredients. Consequently, they are found in substantially higher concentrations on ground than during flight. There was no significant difference between the smoking and non-smoking area.

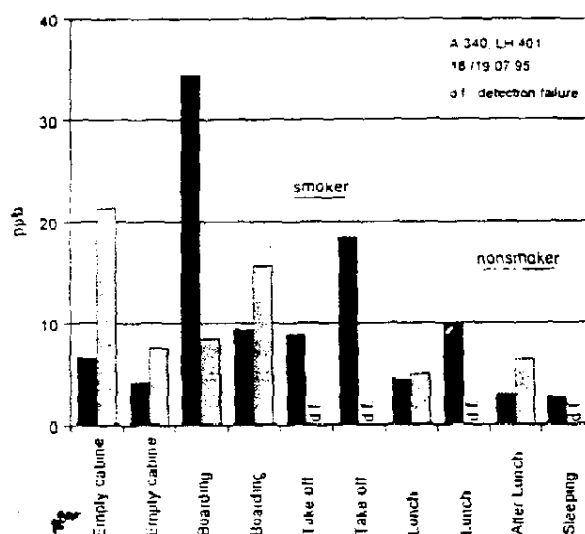


Fig.8: concentration progress of aliphatics

A toxicological evaluation of the results was performed by the Institute of Hygiene and Environmental Medicine, University of Gießen, Germany [3]. The main statements about the determined VOC concentrations are:

- Most of the substances found in cabin air are also present in indoor air e.g. of homes and therefore present no unusual exposure situation
- Wherever the detected values could be compared to existent or proposed indoor guide values, these values were not exceeded.
- Wherever the MAK-values were used for comparison, these values were not exceeded. This also applies in most cases when an appropriate safety factor of 100 is applied.
- A notable exception is nicotine in the air of the smokers' cabin, where concentrations approaching MAK-values were determined.

## Conclusion

Compared to other normal health risks nor a comfort risk

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## Inclusion

Compared to other „normal“ indoor atmospheres [5-10] the obtained results indicate neither more relevance to health risks nor a comfort restriction.

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